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ABSTRACT

Whether in carrier flight operations, resupply at sea, antisubmarine warfare, amphibious landings, sea search and rescue, or ship routing, sea conditions, at the place and time the operation is being conducted, become vitally important. The success or failure of any operation being conducted in an ocean environment is greatly dependent upon the extent to which the operation is affected by the sea. Therefore, this programmed lesson was developed to help students learn about the life cycle of an ocean wave. The information presented extends from the time of a wave's formation through its dissipation. The program is designed to allow students to progress through the subject matter at their own speed. Since it is written in linear format, it is suggested that students proceed through the program from "frame" to succeeding "frame." A list of lesson objectives is included. (Author/JN)

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BASIC PRINCIPLES OF SEA AND SWELL
A
PROGRAMMED UNIT OF INSTRUCTION

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October, 1984

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BASIC PRINCIPLES OF SEA AND SWELL

INTRODUCTION

Whether in carrier flight operations, resupply at sea, antisubmarine warfare, amphibious landings, sea search and rescue, or ship routing, sea conditions, at the place and time the operation is being conducted, become vitally important. The success or failure of any operation being conducted in an ocean environment is greatly dependent upon the extent to which the operation is affected by the sea.

This program has been written to aid you in learning about the life cycle of a wave. The information presented extends from the time of a wave's formation through its dissipation.

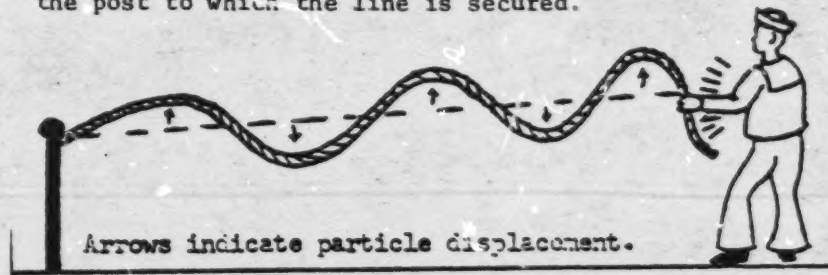
BASIC PRINCIPLES OF SEA AND SWELL

OBJECTIVES

Upon completion of this program, students should be able to:

1. SELECT, from given illustrations, those which show the motion and displacement of water particles in a deep-water wave.
2. MATCH definitions of wave characteristics with their correct terms and symbols.
3. LIST the two interactions between wind and water which result in the formation and development of waves.
4. Provided a synoptic-chart sketch depicting an area wherein waves are being developed:
 - a. LIST the two terms by which the area is identified.
 - b. LIST the term used to describe the type of waves developed therein.
 - c. STATE the theoretical wind criteria used to determine the area.
5. LIST the three factors which determine the state of development and the characteristics of sea waves.
6. Under stated conditions, DETERMINE limiting factors to the sea's becoming fully developed.
7. SELECT true statements about the cause and effect of wave groups becoming superimposed.
8. COMPLETE statements about energy distribution, direction of movement, and conversion of sea waves.
9. LIST the three processes which result in the modification of wave characteristics after the waves depart the fetch.
10. IDENTIFY statements contrasting the appearance and characteristics of sea waves and swell.
11. COMPLETE statements about the velocity of swell waves and groups and the energy transfer process.
12. SELECT true statements about the effect ocean-current and sea-wave encounters have upon swell.

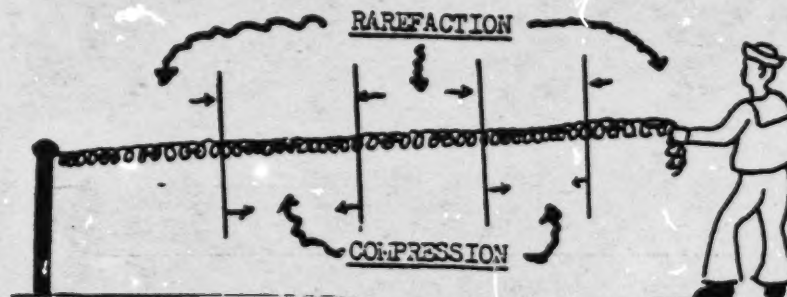
1. When looking out across an ocean surface, one immediately gets the impression that the entire water surface is moving along horizontally in the direction, and with the speed, of the waves. In reality, this is not the case; the motion of ocean waves is far more complex. The illustration below shows a man "whipping" the free end of a piece of line. The whipping action is imparting ENERGY to the line. This energy is traveling in an undulating (upward and downward) motion through the line toward the post to which the line is secured.



The wave created by the man's action is termed a TRANSVERSE wave. Careful examination of the Figure reveals that, in a transverse wave, particle (line) displacement is perpendicular/parallel to the direction of wave travel. (circle one.)

Perpendicular

2. Let's consider another simple wave motion. For this example, we are going to replace the length of line with a similar length of spring. Further, instead of whipping the spring, we are going to compress it by taking several turns on it, and then release it quickly. The diagram below depicts the resultant motion.

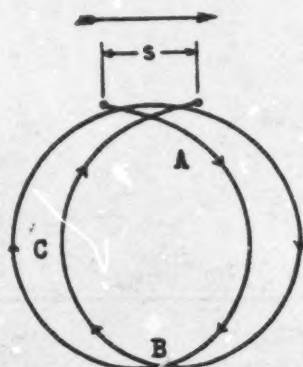


The wave created by this action is called a LONGITUDINAL wave. Careful examination of this diagram reveals that, unlike a transverse wave, particle displacement in a longitudinal wave is perpendicular/parallel to the direction of wave travel. (circle one)

Parallel	3. Ocean waves, as a result of their complex motion, are neither true transverse nor true longitudinal waves, but a composite of the two. This being the case, we can expect particle displacement in ocean waves to be both _____ and _____ to the direction of wave travel.
Perpendicular Parallel (any order).	4. The water particles in an ocean-surface wave, although displaced vertically, follow a circular or an elliptical orbit with the passage of the wave. This orbital motion is illustrated in the diagram below. A passing ocean wave causes the water particles to _____ in a _____ or an _____ motion.
Orbit Circular Elliptical	5. As a wave crest passes, the surface water particles move in the direction of wave travel. As the trough passes, the motion of the water particles is in the opposite direction. Particle speed within the orbit is not uniform, but is greatest near the top of the orbit (water surface). As a result of this orbital motion, there is some horizontal mass movement of surface water in a direction <u>the same as/opposite to wave travel.</u> (circle one)

The same as

6. The orbital motion of water particles within a wave and the horizontal displacement resulting from two complete wave cycles are illustrated below.



= Direction of wave motion

S = Horizontal displacement during two complete wave cycles; comparative distance has been greatly exaggerated for purposes of illustration.

Refer to the diagram above to complete the following statements.

- Rotational speed of the water particles is greatest at point _____.
- Rotational direction of the water particles is opposite wave motion at point _____.

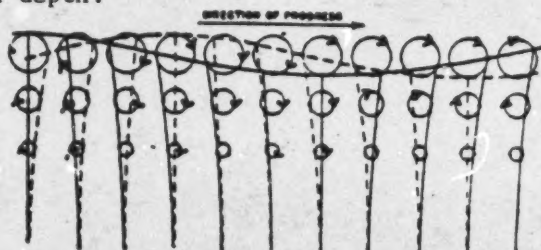
a. A

b. B

7. Because of the orbital motion of the water particles within a surface wave, actual horizontal mass movement of the water particles with each wave cycle is quite small/large.
(circle one)

Small

8. The rotational motion of the surface water particles within a wave also affects those particles beneath the surface and causes them to move in circular orbits. The radius of the orbits of particles beneath the surface decreases with depth, approaching zero at a depth equal to about one-half the distance between surface wave crests. The diagram below illustrates the movement of water particles in a wave. The circles show the paths in which the water particles move and how their radii change with depth.



The diagram above shows that the radius of the circle in which water particles orbit beneath the surface of a wave increases/decreases with depth.

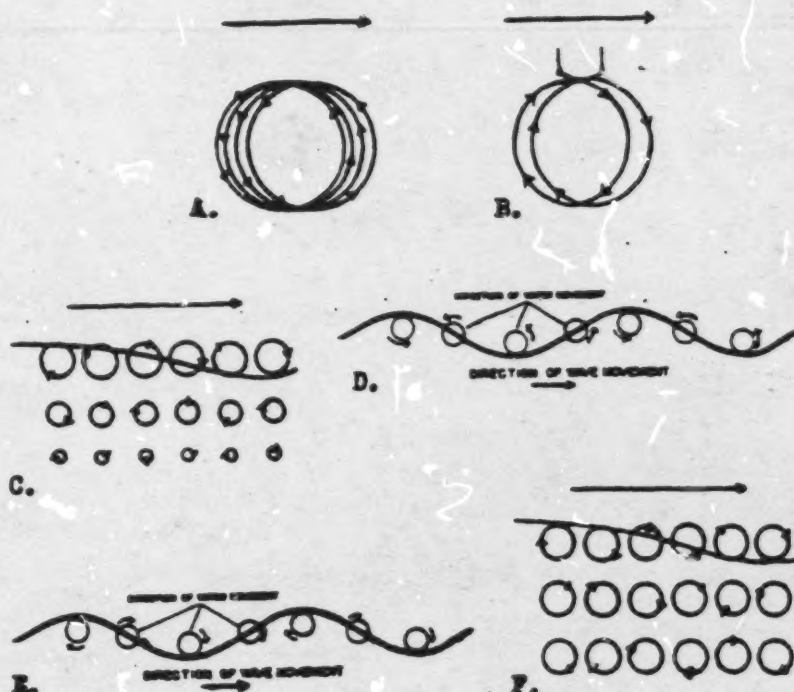
(circle one)

decreases

9. In ocean waves, water serves as the medium through which energy moves. While waves serve as a vehicle for the transport of energy across the surface of the oceans, the horizontal mass transport of water resulting from wave action alone is small/considerable (circle one)

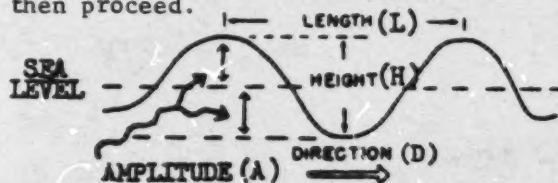
small

10. Circle the letters of the diagrams below which illustrate the motion and displacement of water particles in an ocean wave. Arrows show direction of wave movement.



B.
C.
E.

11. The illustration below shows a simple wave and a few of its characteristics. Examine the diagram carefully, then proceed.

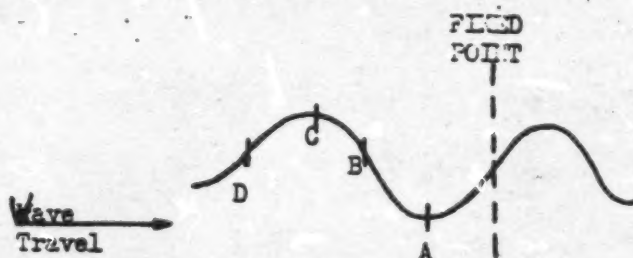


The statements below describe the wave characteristics shown in the diagram above. Using the illustration as a guide, identify each characteristic and write its proper title and abbreviation on the space provided.
(Continued on next page)

- a. The vertical distance measured (in feet) from the wave crest to sea level OR from sea level to the bottom of the trough is the wave's _____.
- b. The horizontal distance measured (in feet) from crest to crest or trough to trough is the wave's _____.
- c. The vertical distance measured (in feet) from the lowest point of the trough to the highest point of the crest is the wave's _____.
- d. "A figure, expressed in tens of degrees in relation to true north, to indicate the bearing from which a wave is coming," defines a wave's _____.

- a. Amplitude (A)
- b. Length (L)
- c. Height (H)
- d. Direction (D)

12. The period (T) of a wave is the time (in seconds) it takes for one complete wave length (L) to pass a fixed point. According to this definition, the period of the wave below would be the amount of time necessary for point _____ to pass the fixed point.



Since wave period is a measurement of time, the symbol used to represent this characteristic is a/an

S / T / M
(circle one)

D
T

13. Note that wave amplitude, height, and length are all measured in feet/meters/yards; whereas wave period is measured in meters/seconds/minutes.
(circle one)

Feet
Seconds

14. The frequency (f) of an ocean wave refers to that fractional part of the wave, or the number of complete waves, that passes a fixed point in one second. The frequency of a sine wave is the reciprocal of its $\frac{1}{T}$ period (T) and can be determined by the formula $f = \frac{1}{T}$. If 120 complete waves pass a fixed point in one minute, the frequency of these waves is _____ cycles per second.

2

15. The reciprocal of a wave's period is its _____ which is represented by the symbol "_____". A wave having a period of 10 seconds has a frequency of $1/10$ (one-tenth) cycle per second. One-tenth of this complete wave passes a given point in one second. An ocean wave having a wave length (L) of 45 feet and a period (T) of 15 seconds would have a frequency (f) of _____ cycles per second.

frequency

f

$1/15$

16. The speed with which a wave crest moves through the water is known as the wave, or phase, VELOCITY (C); it is usually expressed in feet per second. With simple sine waves, phase velocity is equal to the wave length divided by the period ($C = \frac{L}{T}$). For example, if a wave's length is 45 feet and its period is 15 seconds, its phase velocity is 3 feet per second. ($C = \frac{45}{15}$). An ocean wave has a height of 4 feet, a length of 25 feet, and a period of 10 seconds. Using information given thus far in the program, determine:

a. Frequency

b. Phase velocity.

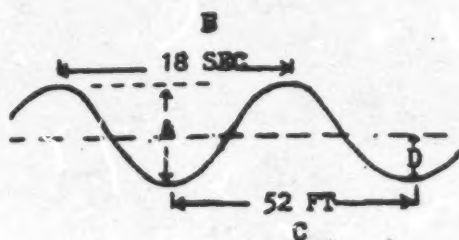
a. _____

b. _____

a. $1/10$ cycle per sec.

b. 2.5 feet per sec.

17. In the spaces provided, indicated which wave characteristic is represented by A, B, C, and D on the diagram



A. _____

B. _____

C. _____

D. _____

- A. Height
- B. Period
- C. Length
- D. Amplitude

18. Match the definition of wave characteristics in column A with the correct term from column B.

- | <u>A</u> | <u>B</u> |
|--|--------------|
| 1. A fraction which expresses that portion of a given wave which will pass a fixed point in one second. | a. Height |
| 2. The vertical distance measured from the lowest point of the trough to the highest point of the crest. | b. Velocity |
| 3. A figure, expressed in tens of degrees, to indicate bearing from which a wave is moving. | c. Length |
| 4. The horizontal distance from crest moves through the water. | d. Frequency |
| 6. The vertical distance from wave crest to sea level, or from sea level to the bottom of the trough. | e. Amplitude |
| 7. The time it would take for one complete wave length to pass a fixed point. | f. Thickness |
| | g. Period |
| | h. Direction |

- 1. d
- 2. a
- 3. h
- 4. c
- 5. b
- 6. e
- 7. g

19. Match the wave characteristics in column A with the correct symbol used to represent each in column B.

- | <u>A</u> | <u>B</u> |
|-------------------|----------|
| 1. ____ Height | L |
| 2. ____ Velocity | F |
| 3. ____ Length | A |
| 4. ____ Frequency | f |
| 5. ____ Amplitude | D |
| 6. ____ Direction | T |
| 7. ____ Period | S |
| | H |
| | C |

1. H 2. C 3. L 4. f 5. A 6. D 7. T	20. Any disturbance of the smooth surface of the ocean can be considered a wave. This includes ripples that may be only a fraction of an inch high to the mountainous waves found in a hurricane. In any case, the wind is the driving force which creates ocean _____.
Waves	21. The wind flow over open water is not a smooth flow, but a turbulent one. Thus, turbulence causes a series of pressure fluctuations which develop ripples on the surface of the water. These ripples, or wavelets, are the first step toward _____ formation.
Wave	22. With continued wind flow, the size of the newly formed ripples gradually increases. This increase is the result of an interaction between wind and water. One portion of this interaction is the PUSHING action which results in the transfer of energy from wind to wave simply because the wind pressure is greater on the windward side than it is to leeward.  The diagram illustrates that, on the windward side of a wave, energy is transferred from wind to water via a _____ action.
Pushing	23. The second portion of this interaction, and the more important of the two, is referred to as a DRAGGING action. This dragging occurs on the leeward side of the wave and is caused by the difference in the velocity of the air particles and the water particles.  The diagram shows that, on the leeward side of a wave, energy is transferred from wind to water via a _____ action.

Dragging

24. As this interaction continues, the waves become larger. Their growth results in the exposure of more water surface for the wind to act upon and allows additional wave growth with continued wind flow.

In the spaces provided below, write the two interactions between wind and water which result in the formation and development of waves.

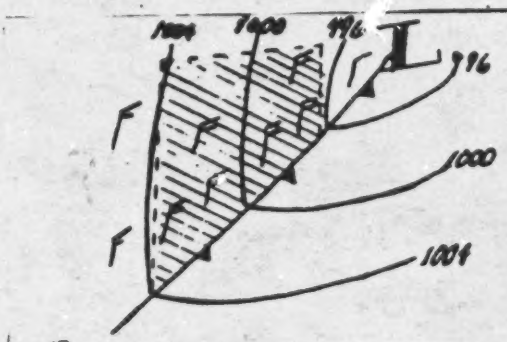
a. _____ b. _____

Pushing

Dragging

(any order)

25. The area wherein waves are being developed is called the GENERATING AREA or FETCH. In this area, waves are being generated by a wind of theoretically constant direction and speed. ("Theoretically" refers to the ideal case.) The shaded portion of the synoptic chart below illustrates a typical generating area (fetch which meets the wind requirements previously stated).



In the generating area (fetch), wind flow is assumed to be constant in both _____ and _____.

Direction

Speed

26. As long as waves remain in their generating area (fetch) and the wind remains constant over the area, the waves within the area are termed SEA waves. An area having constant wind speed and direction, and in which waves are being developed, may be referred to as either a _____ area or a _____.

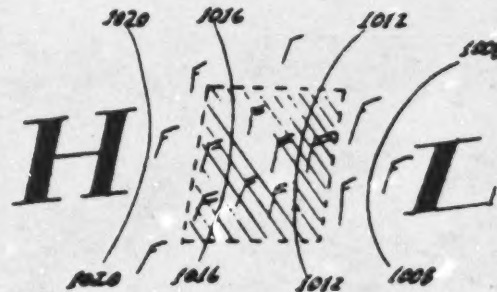
Waves within this area are termed _____ waves.

Generating

Fetch

Sea

27. The shaded portion of the synoptic chart below depicts an area in which waves are being developed. Refer to the chart in completing the items below it.



- The two terms used to identify this area are (1) _____ and (2) _____
- The term used to describe the waves being developed therein is _____ waves.
- In this area, wind flow is assumed to be _____ in both _____ and _____.

a. Fetch
Generating
Area

b. Sea

c. Constant
direction
speed

28. Unless otherwise limited, a sustained wind flow within the fetch will result in a fully developed sea. The sea is said to be fully developed when the dissipation (loss) of energy by the waves balances the work being done on them (energy received) by the wind. When the energy dissipated by the waves equals the energy received, the sea is said to be _____.

Fully
developed

29. When the sea has become fully developed, the waves have attained the maximum height possible under the existing wind conditions. If someone told you that the sea had reached its fully developed state, you would know that the waves within the fetch had attained their _____ height.

maximum	30. Three factors determine the extent of the sea's development within a fetch. These factors are: a. Wind speed - in knots b. Duration - length of time wind has blown c. Fetch length - nautical miles of open sea over which the constant wind has blown. If an easterly wind has blown at 20 knots for the past 12 hours over an 800-nautical-mile stretch of open sea, the: Wind speed is _____. Duration time is _____. Fetch Length is _____.
20 knots 12 hours 80 naut. mi.	31. On the lines below, list the three factors which determine the stage of development of sea waves. a. _____ b. _____ c. _____
Wind speed Duration time Fetch length (any order)	32. Through research, it has been determined that, for a given wind speed, there is a minimum duration time and fetch length required in order for the sea to attain its fully developed state. If either, or both, of these minimums is not reached, sea development is limited by that factor. If a wind speed of 10 knots requires a fetch of 10 nautical miles and a duration time of 2 1/2 hours in order for the sea to develop fully, but the wind only blew at 10 knots for 1 1/2 hours, the sea (as to becoming fully developed) would be referred to as being _____ limited.
Duration	33. In like manner, if the fetch were less than that required for a given wind speed, the sea would then be _____ limited.

Fetch

34. Referring to the example in frame 32, assume we have a 10 knot wind but that this wind has blown over only 7 nautical miles for a period of 1 1/2 hours. The sea, under these conditions, would be limited by:

- (Choose one) a. Fetch
b. Duration
c. Both fetch and duration

c.

35. The table below shows the minimum fetch (F_{min}) and minimum duration (t_{min}) required to generate a fully developed sea for various wind speeds (V kts.). Use this table to complete the statements below it.

V knots	10	12	14	16	18	20	22	24	26	28
F_{min} NM.....	10	18	28	40	55	75	100	130	180	230
t_{min} hr.....	2.4	3.8	5.2	6.6	8.3	10	12	14	17	20

V knots	30	32	34	36	38	40	42	44	46
F_{min} NM.....	280	340	420	500	600	710	830	960	1100
t_{min} hr.....	23	27	30	34	38	42	47	52	57

V knots	48	50	52	54	56
F_{min} NM.....	1250	1420	1610	1800	2100
t_{min} hr.....	63	69	75	81	86

- a. A wind of 22 knots requires a minimum duration time of _____ hours over a fetch of _____ nautical mi.
- b. A fetch of 280 nautical mi. requires a wind speed of _____ kts. and a duration time of _____ hrs.

a. 12; 100

b. 30; 23

36. The following table is the same as that used on the preceding page. Use the table to determine the limiting factors (with regard to the sea's becoming fully developed) under conditions as stated below. In the space provided, write the word FETCH, DURATION, BOTH or NONE to indicate your solution.

V knots	10	12	14	16	18	20	22	24	26	28
F_s NM.....	10	18	28	40	55	75	100	130	180	230
t_s hr.....	2.4	3.8	5.2	6.6	8.3	10	12	14	17	20

V knots	30	32	34	36	38	40	42	44	46
F_s NM.....	280	340	420	500	600	710	830	960	1100
t_s hr.....	23	27	30	34	38	42	47	52	57

V knots	48	50	52	54	56
F_s NM.....	1250	1420	1610	1800	2100
t_s hr.....	63	69	75	81	88

a. WIND 16 kts.
 FETCH 30 NM
 DURATION 6.6 hrs.

LIMIT: _____

b. WIND 12 kts.
 FETCH 60 NM
 DURATION 10 hrs.

LIMIT: _____

c. WIND 25 kts.
 FETCH 180 NM
 DURATION 8 hrs.

LIMIT: _____

d. WIND 38 kts.
 FETCH 200 NM
 DURATION 24 hrs.

LIMIT: _____

e. WIND 32 kts.
 FETCH 400 NM
 DURATION 36 hrs.

LIMIT: _____

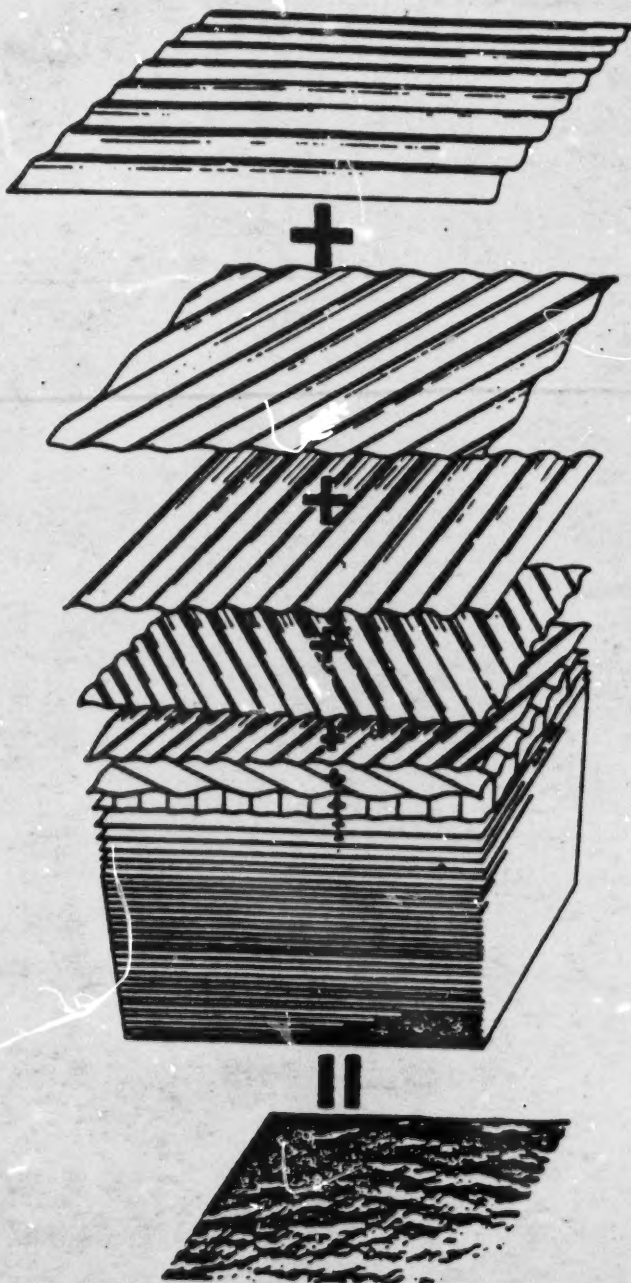
f. WIND 30 kts.
 FETCH 100 NM
 DURATION 24 hrs.

LIMIT: _____

(answers opposite frame 37)

Unfortunately, actual ocean waves are not simple sine waves. Instead, they are the result of many different groups of sine waves becoming superimposed as the groups move with different speeds and directions. The principles regarding superimposition of wave groups are shown in the illustration at left.

In nature, a wider range of amplitudes would be present among the wave groups which together form the composite sea surface.



This illustration should help you understand the sea's confused appearance in the generating area, wave distortion, and the way energy becomes unequally distributed.

(NO RESPONSE)

A sum of many simple sine waves makes a sea

- a. FETCH
- b. NONE
- c. DURATION
- d. BOTH
- e. NONE
- f. FETCH

37. Wave groups become superimposed upon each other, because the groups are moving in different _____ at different _____.

directions
velocities

38. Superimposition of wave groups gives the sea a _____ appearance and causes the individual wave group's characteristics to become _____.

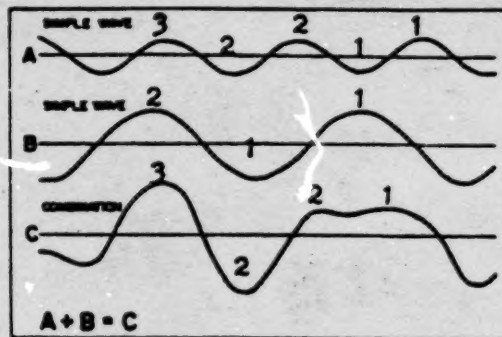
Confused
Distorted

39. When the crests or troughs of superimposed waves are in phase, the amplitude of the combined crest or trough is increased. Remember, in phase - increased!

Conversely, if the crests and troughs of the individual waves are out of phase, a dampening or flattening effect results and amplitudes are decreased. When the crests and troughs of superimposed wave groups are out of phase, the energy of one group is working against that of the other group, and a general _____ or _____ of the waves results.

Dampening
Flattening
(any order)

40. The following illustration shows two simple sine waves (A & B) and the result of their having been combined, or superimposed (C).



Refer to the illustration above in completing the following statements.

- a. The energy contained in troughs #2 (A) and #1 (B) and that contained in crests #3 (A) and #2 (B) have combined to increase/decrease trough #2 and crest #3 of wave "C". (circle one)
- b. Crests #1 and #2 of wave "C" are the result of trough #1 (A) and crest #1 (B) working together/in opposition. (circle one)

40. (cont.)

NOTE: Crests #1 and #2 of wave "A" have increased slightly, as shown in wave "C". However, this has been at the expense of trough #1 (A) and crest #1 (B).

a. Increase

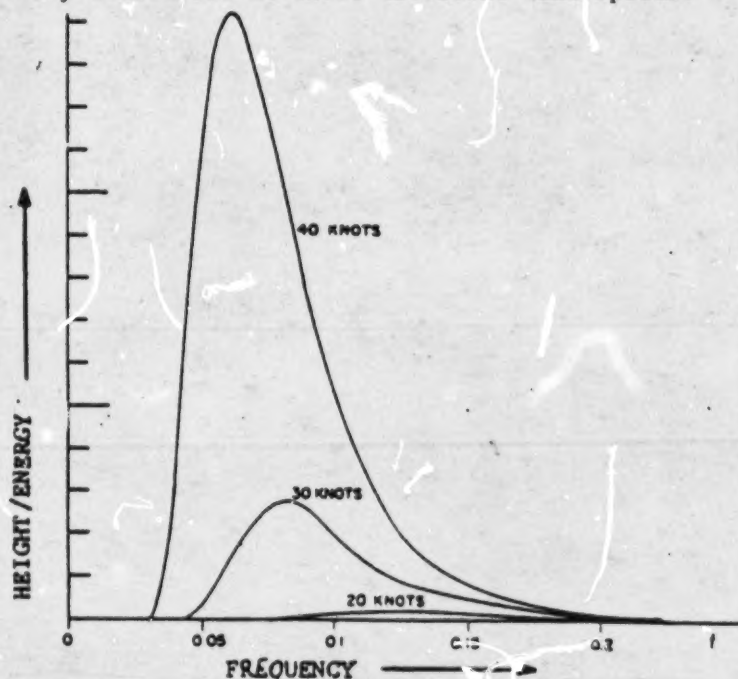
b. In opposition

41. Select, from the following, those statements which are TRUE about the cause and effect of wave groups becoming superimposed. Place a "T" beside selections.

- ☐ a. Superimposition of wave groups results in the sea's having a chaotic, or confused, appearance.
- ☐ b. Wave groups become superimposed because of the difference in direction and velocity with which they are moving.
- ☐ c. When the crests and troughs of superimposed wave groups are in phase, amplitudes of the combined crests and troughs are decreased.
- ☐ d. When wave groups become superimposed, characteristics of the individual wave groups become distorted.
- ☐ e. When the crests and troughs of superimposed wave groups are out of phase, amplitudes of the crests and troughs of the combined waves become dampened or flattened.
- ☐ f. When out of phase, the combined energy of superimposed wave groups is working together.

- T a.
 T b.
 c.
 T d.
 s e.
 f.

42. In the generating area, wind and superimposition combine to cause small waves to form upon larger waves, and high waves to follow low waves in a completely mixed-up manner. This results in a wide range of wave heights, periods, and frequencies. The sum of all the characteristics of the combined wave groups present is called the wave or sea SPECTRUM. The graph below illustrates the wave spectrum for a fully arisen sea at three different wind speeds.



The graph shows that for each wind speed, there is a range of:

- a. _____ b. _____ / _____

- a. Frequency
b. Height/
energy

43. When we consider the sum of all the characteristics of the individual wave groups present in a sea, the term " _____ " may be used.

Spectrum

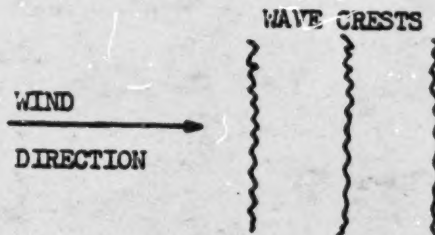
44. The area under each curve in the graph represents the amount of energy present. The peak in each curve shows that the waves created by each wind speed are concentrated around a certain frequency/length and height/speed.
(circle one)

- Frequency
Height

45. The frequency of the waves with the most energy for a given wind speed is termed " f_{max} ." A knowledge of f_{max} aids greatly in making wave height predictions, for the majority of the waves will fall into the height range corresponding to this frequency. On the graph, the spectrum for the waves generated by a 40-knot wind shows that a frequency of 0.07 would be the _____ of these waves.

f
max

46. Wave crests are normally aligned perpendicular to the wind and move in the direction toward which the wind is blowing. In the generating area, individual crest movements appear to vary by as much as 20° to 30° from the prevailing wind direction.



Normal wave-crest alignment is _____ to the prevailing wind flow, but wave-crest movement is _____ to it.

Perpendicular
Parallel

47. You should remember that wind waves are _____ in motion and that mass water movement is _____. Consequently, wave movement is not affected by coriolis force and, once formed, sea waves continue to move in a straight path. Sea waves continue to move in a direction parallel/perpendicular to the wind direction at (circle one) the time of their formation.

Energy
Small
Parallel

48. When sea waves become separated from the wind which generated them, they become known as SWELL. This separation may result from the sea waves moving out of the fetch area or as a result of significant changes in the wind direction and/or speed creating a new fetch. The term SWELL refers to sea waves which have become separated from the _____ which _____ them.

Wind
Generated

49. When sea waves move out of the fetch or come under the influence of a wind other than that which generated them, the sea waves become known as _____.

Swell	50. Complete the following statements, with regard to the energy distribution, direction of movement, and conversion of sea waves. a. When the combined characteristics of all the wave groups present in the fetch are considered, the total is referred to as the sea or energy _____. b. Because of the direct relationship between wave height, energy, and frequency, for every wind velocity there is a specific _____ around which the maximum energy is concentrated; this is commonly referred to as the _____. c. In normal sea-wave alignment and movement, wave crests are aligned _____ to the dominant wind flow and move _____ to it. d. Any significant change in wind _____ and/or _____, or movement of sea waves outside their fetch area, results in the conversion of the waves into _____. e. Deep-water waves, being unaffected by coriolis force, always continue to move in a _____ path.
a. Spectrum b. Frequency f_{max} c. Perpendicular d. Direction speed swell e. Straight	51. When sea waves move out of the fetch into an area of calm, there immediately begins a gradual energy loss which causes changes in their characteristics to occur. As sea waves become swell, changes occur in their characteristics as a result of an energy <u>gain/loss</u>. (circle one)
loss	52. The energy loss results from the resistance to motion of the calm water presently at rest. As the wave (energy) pregoreses through this area, energy is used to overcome the force of gravity and set the calm water in motion. Waves invading an area of calm seas must overcome a resistance to motion; this results in the waves losing a portion of their _____.
Energy	53. Since a direct relationship exists between the amount of energy a wave posseses and the wave's height, as the waves lose energy, their height will <u>increase/decrease</u> accordingly. (circle one)

Decrease

54. In addition to the changes in wave characteristics brought about by the energy loss, there are two other important processes which cause wave characteristics to change. These two processes are DISPERSION and ANGULAR SPREADING.

Dispersion means to separate into component parts. You learned earlier that within the fetch there are wave groups possessing a wide range of characteristics. Upon leaving the fetch, those wave groups possessing the greater velocities out-distance the others. Thus, each wave becomes a part of a group which is traveling in the same direction and possesses the same

_____ as itself.

Character-
istics

55. Angular spreading is the lateral (sideways) extension of sea waves as they move out of the fetch; it results from the slight variations in wind direction within the fetch.

Two important processes, other than routine energy loss, which cause wave characteristics to change are

_____ and _____
_____.

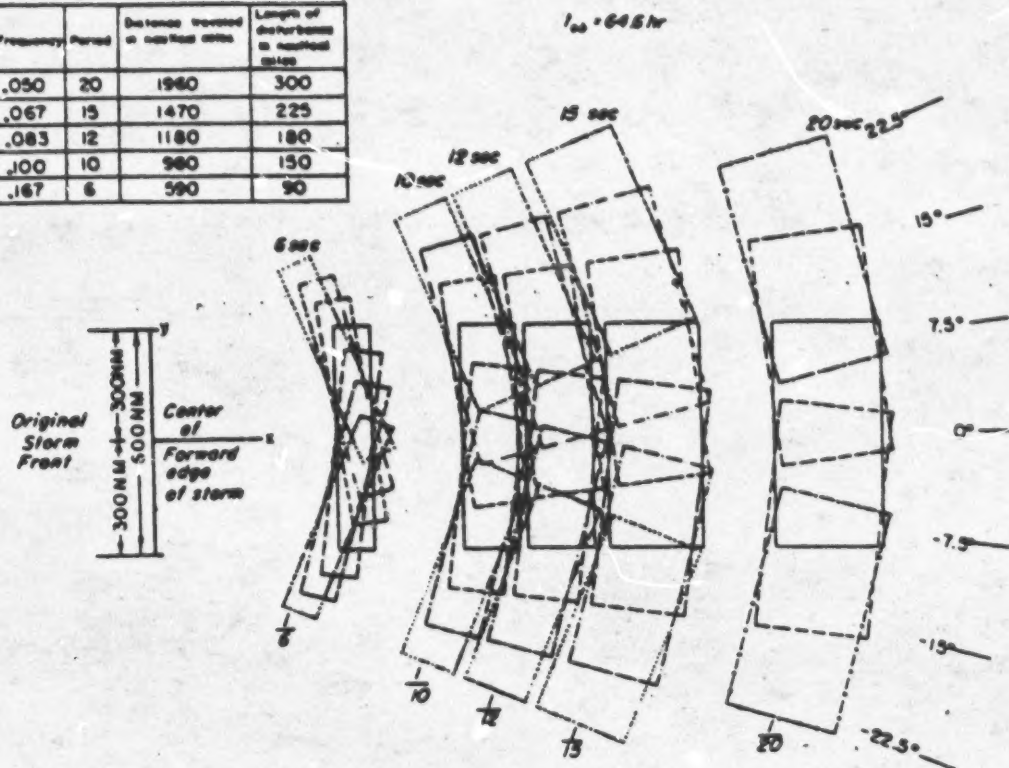
Dispersion

Angular

spreading

56. The graph below illustrates the dispersion and angular spreading of waves discussed in the two preceding frames. Time of the observation is 64.6 hours after the waves departed the fetch. Note that the waves possessing a period of 20 seconds have traveled more than three times the distance of those having a period of 6 seconds. Also, note lateral extension (angular spreading) has caused the 600 NM. Leading edge of the fetch to become spread out to where the most distant wave groups cover an area of nearly 1800 NM in width.

Frequency	Period	Distance traveled at 64.6 hr	Length of disturbance in modified fetch
.050	20	1960	300
.067	15	1470	225
.083	12	1180	180
.100	10	980	150
.167	6	590	90



(NO RESPONSE)

Sea

57. Swell takes on a more regular appearance. Crests become rounded and much lower because of energy loss. Periods become much longer because of dispersion. The length of swell crests is at least six or seven times the distance between crests. Long, well-rounded waves, having a crest length of six to seven times their wave length, describes the appearance of _____.

Swell

58. Because dispersion results in the separation of waves into groups having similar characteristics, swell will possess a much narrower range of frequencies than sea waves.

Within the fetch, sea waves possess a wide range of characteristics; whereas, upon becoming swell, waves possess a much narrower/wider range of characteristics.
(circle one)

Narrower

59. Considering their regularity and similarity of characteristics, sea/swell waves are far more predictable.
(circle one)

Swell

60. Although technically termed "swell" as soon as they depart the fetch, the modification of sea wave's characteristics to those normally associated with swell requires time.

The following graphs illustrate this modification as it occurs. These graphs may be considered as another view of the dispersion process illustrated in the graph in frame 56.

These graphs were made by a wave-recording instrument, designed to measure and record the heights of waves as they pass by a ship at sea. Figure A shows sea wave records; those in figure B are in the transition stage, or in-between; those in figure C are records of swell.

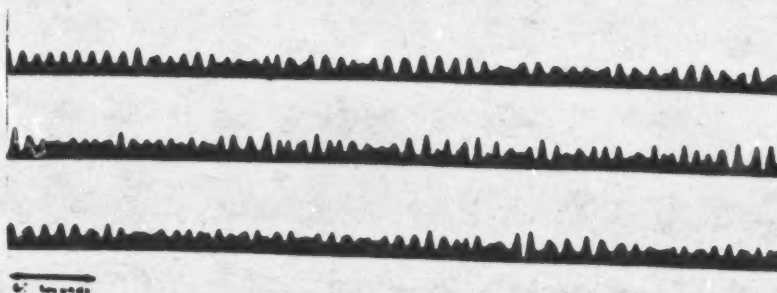


Figure A.--Sea wave records.

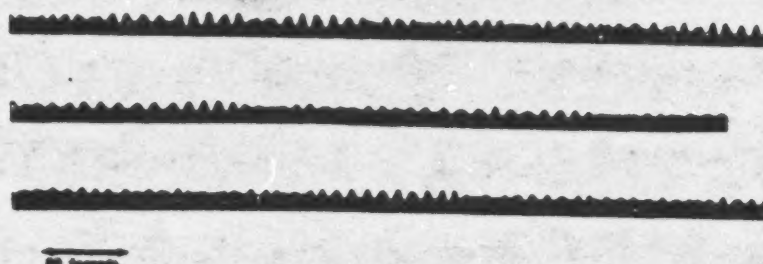


Figure B.--The records of in-between waves.

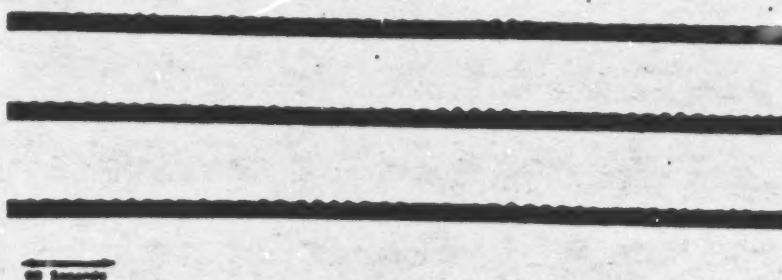


Figure C.--Swell wave records.

Refer to the wave recordings to complete the following statements:

- a. Waves showing the greatest degree of regularity are those shown in the sea/in-between/swell wave records.
(circle one)
- b. Waves having the greatest amplitudes are those shown in the sea/in-between/swell wave records.
(circle one)
- c. Waves having the longest periods are those shown in the sea/in-between/swell wave records.
(circle one)
- d. Waves showing characteristics common to both sea waves and swell are best illustrated in the wave records of the sea/in-between/swell waves.
(circle one)

a. Swell b. Sea c. Swell d. In-between	61. In the space provided, write the word SEA or SWELL to indicate whether the following statements describe wave conditions as found within, or outside, the fetch. _____ a. Wave crests are sharp, angular, and irregular; distance between crests is short. _____ b. Crest length of the wave is at least six to seven times the wave length. _____ c. Wave crests are well-rounded and regular; wave periods are long. _____ d. Wave heights, periods, and frequencies cover a wide range. _____ e. Crest lengths are relatively short; usually about two or three times the distance between crests. _____ f. Wave characteristics are similar and have a narrow frequency range.
<u>Sea</u> a. <u>Swell</u> b. <u>Swell</u> c. <u>Sea</u> d. <u>Sea</u> e. <u>Swell</u> f.	62. Movement of swell is sometimes complex. This is because of the differences between <u>phase</u> (wave) velocity and <u>group</u> velocity and, also, because of the <u>energy transfer</u> that occurs along the route of travel. For example, the individual waves within a swell group move at a speed which is TWICE that of the entire group. Or, using proper terminology, we would state: Phase velocity is _____ that of _____ velocity.
Twice Group	63. Conversely, group velocity is equal to _____ that of phase velocity.
One-half	64. Before going further into these relationships, let's first discuss energy transfer, and then examine the combined processes. When an individual swell wave moves within an area of calm sea, only one-half of the wave's energy continues to advance with the speed of the wave. Therefore, a swell wave, moving into an area of still water, leaves its energy behind. _____

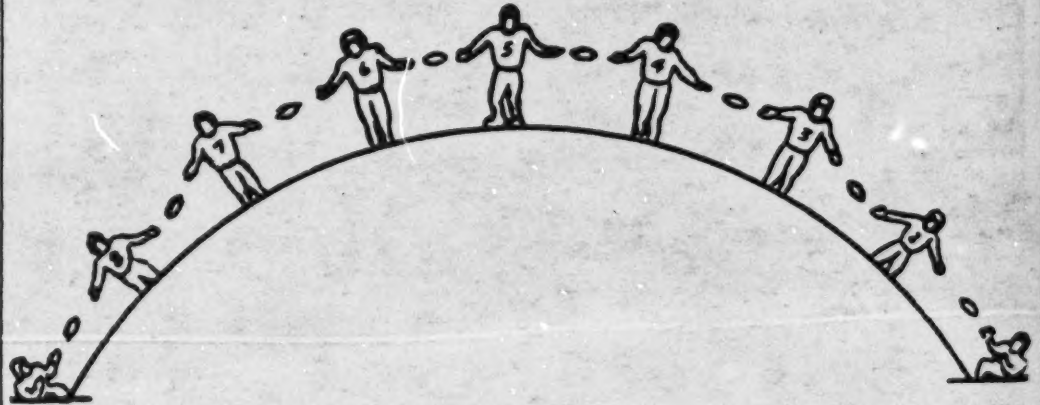
one-half

65. The lead wave of an advancing group continues to lose one-half of its remaining energy upon completion of each wave cycle. Upon completion of one cycle after entering still water, for example, the lead wave would retain but 50% of its original energy. On continuing its advance, the half-energy wave again loses one-half its remaining energy upon completion of the next wave cycle. After two complete cycles, this wave would possess only _____% of its original energy.

25

66. This "energy split" process continues until the wave's energy is completely exhausted and the wave is dead! When this occurs, the second wave in the group becomes number one.

Meanwhile, what has happened to the ORIGINAL number one wave's energy? We have said that, with each wave cycle, one-half of the wave's energy was left behind. The number two wave of the group has been absorbing that energy which was left by number one; and wave two's half energy has been passed to number three, and three's to four, etc. And so, with all of this energy being lateralised (transferred) to the rear like the proverbial football, and with the last wave in the group passing 50% of its energy rearward with each cycle, soon we see the formation of NEW waves to the rear which are becoming a part of, and are moving along with, the group.



The football players above represent waves of a group, with the football, itself, representing one-half of each player's energy being lateralised rearward. One can see that by the time two players have each lateralised one-half (50%) of their original energy rearward before being "downed", a new player rushes up to grab the ball at the rear of the group and keeps the energy moving.

In reality, following this "split energy" formula, only a small portion of our now defunct number one wave's energy has been lost to the sea; rather, most of it has been transferred rearward through this energy transfer process.

Keeping the "transfer of energy" in mind, let us see whether we can further illustrate it in such a manner so as to verify our aforementioned phase vs group velocities.

(NO RESPONSE)

	67. Use the diagram on the following page as reference in completing frames 67 through 70. In the first sentence, line "A", the middle wave of the group is wave number _____.
5	68. In the second sequence, line "B", both wave #1 and wave #9 have given up one-half of their energy. Upon completion of the next cycle, however, (line "C"), wave #2 has absorbed that energy given up by #1 and begun its transfer rearward through the successive waves. With the waves ahead each progressively passing energy to the rear, the result is that wave #9 not only is restored to full energy, but wave _____ is formed.
10	69. With continued repetition of wave cycles and energy transfer, by the time we arrive at the seventh sequence (line "G") the total number of waves to have passed the reference point is _____. The wave which NOW represents the middle wave of the group, however, is wave number _____.
6 8	70. Thus, with a total of six individual waves having passed the reference point, but with the addition of three newly formed waves to the rear of the group as a result of the transfer of energy, it CAN be said that phase velocity is _____ that of the group.

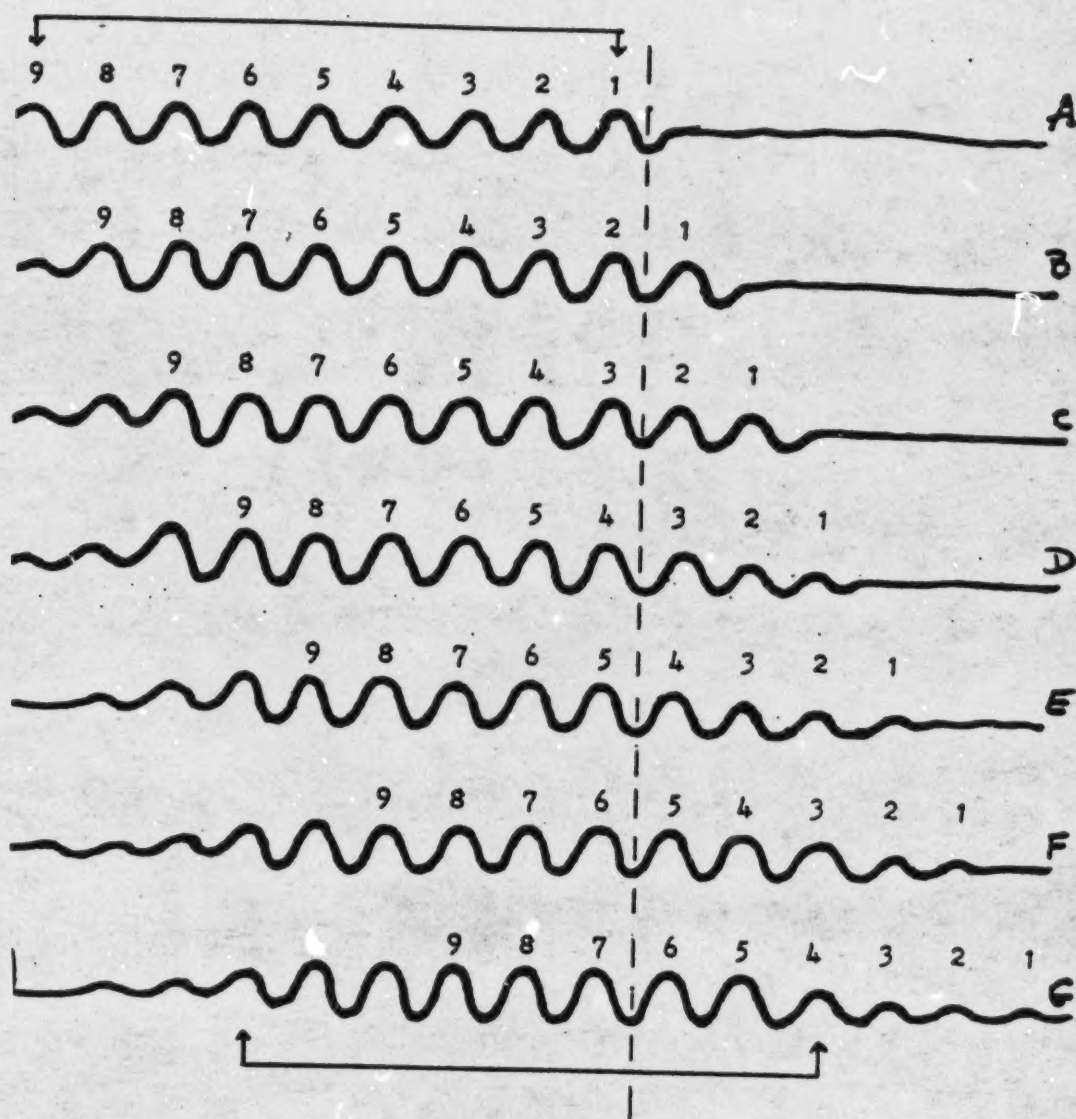
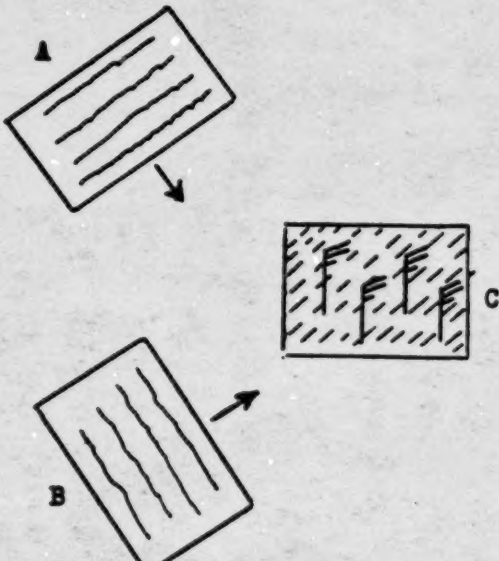


Diagram illustrating phase velocity versus group velocity of swell group entering area of calm. Vertical-dashed line is reference point. Energy distribution and transfer within the group as it advances is also shown.

Twice	71. For the sake of simplicity, the swell group in the preceding illustration was kept very small. In nature, there is no way of predicting the number of waves which will be within the group, because of the factors governing wave formation. Further, the group will undergo modification of characteristics between the time it departs the fetch and arrives at the forecast point. (NO RESPONSE)
	72. Complete the following statements regarding the velocity of swell waves, swell groups, and the energy transfer process. a. A swell group moves with a velocity which is equal to _____ that of its waves. b. As a swell wave advances within an area of calm, _____ % of its energy is left behind. c. Because of the transfer of energy process, as a swell group advances and its leading waves die out, new waves are formed at the _____ of the group. d. The speed of advance of the individual waves within a swell group is _____ that of the entire group.
a. One half b. 50 c. Rear d. Twice	73. Thus far in our discussion regarding swell, we have concerned ourselves only with that which occurs when swell waves enter an area of calm seas after having departed the fetch. Suppose, however, that instead of continuing to pass through calm seas, our swell waves encounter ocean currents, following or opposing winds, or waves generated by other storms. What effect, if any, would these conditions have upon our swell? (NO RESPONSE)
	74. Waves moving through a region where there is a current will be affected by that current. If the current is moving in the same direction as the waves, the tendency will be to increase the length and decrease the height, without altering the period of the waves. When waves encounter a current which is moving in the same direction as themselves, the result is that individual wave heights are <u>increased/decreased</u> and (circle one) that wave lengths become <u>longer/shorter</u>. (circle one)

Decreased Longer	75. In order to increase the length of the waves without altering their period, phase velocities would also have to <u>increase/decrease</u> proportionately. (circle one)
Increase	76. When waves encounter a current which is moving in the opposite direction, the tendency will be to decrease wave lengths and increase their heights. The stronger the current, the greater the effect. Whenever waves encounter a very strong current moving in the opposite direction, wave heights will be <u>increased/decreased</u> and wave lengths will be <u>increased/decreased</u> more or less than if the current were one of lower velocity. (circle one) (circle one)
Increased Decreased More	77. When currents of the same velocity are considered, than which is moving in the opposite direction to the waves will have the greatest effect on wave heights. Velocities being equal, wave heights are affected most by currents moving in the _____ direction.
Opposite	78. In situations were traveling swell obliquely (at an angle) encounters waves being generated by a local wind, the traveling swell wave's energy will be greatly dissipated. The illustration on the following page depicts two swell-wave groups (A & B) approaching a fetch (C). 

As swell group A passes through the fetch, superimposition occurs, which causes immediate combined wave build-up. Every time a wave builds beyond a certain height, little white caps form and the crests of the waves break off and plunge into the trough ahead. Each time breaking occurs, a certain amount of energy is dissipated. Part of this energy is restored to the local waves as the wind continues to blow. The energy dissipated from the traveling waves cannot be replenished; therefore, a corresponding decrease in the height of those waves results. To what extent the swell will be diminished is dependent upon their height upon entering the fetch and the length of time it takes them to traverse it.

In the case of swell group B entering the fetch, we have opposing forces, one of which already contains all of the energy it will ever possess, and the other is well supplied with energy and has a continuous supply (the wind) available.

This situation results in a very rough and chaotic sea! There are many dependent factors involved: How large the swell was upon entering the fetch, how long the wind has been blowing, etc. In most instances, the swell would never survive to traverse the fetch. Should it survive, the swell wave's energy becomes so nearly exhausted that it dissipates before creating any appreciable disturbance.

In any practical case where swell waves obliquely encounter sea waves, the energy dissipated as a result of the encounter will always be at the expense of the _____ waves.

Swell

79. Select, from the following statements, those which are TRUE with regard to the effect ocean-current and sea-wave encounters have upon swell. Place a "T" beside those you select.
- ____ a. Upon encountering an ocean current moving in the same direction as themselves, swell-wave heights become increased and their lengths shortened.
 - ____ b. When swell waves encounter following or opposing ocean currents, in order for wave heights or lengths to be altered without changing periods, phase velocities must be increased or decreased proportionately.
 - ____ c. Swell waves, entering and transiting a fetch at an oblique angle, will always suffer a loss of energy.

- ☐ d. Considering currents of equal velocity, swell-wave heights will be affected most by those currents which are moving in the same direction as themselves.
- ☐ e. Swell-wave heights become decreased and their lengths increased when they encounter ocean currents moving in the same direction as themselves.

☐ a.

☒ b.

☒ c.

☐ d.

☒ e.

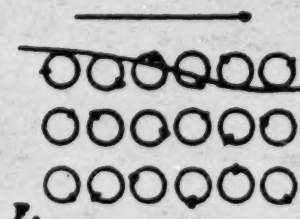
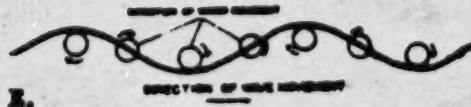
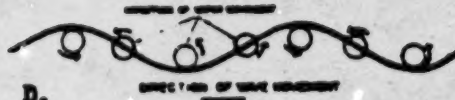
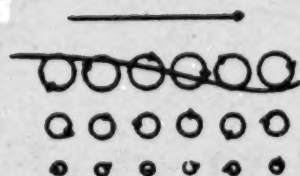
This completes this program on the basic principles of sea and swell. Before you attempt the self test, re-read the program objectives, and be sure you have mastered each one. Review areas which were unclear to you in the program booklet. Review any difficult frames.

When you are certain that you have mastered each objective, attempt the self-test.

BASIC PRINCIPLES OF SEA AND SWELL

SELF-TEST

1. Select, from the following diagrams, those which illustrate the motion and displacement of water particles in a deep-water wave. Arrows show direction of movement. (Frames 1 - 9)



2. Match the definition of wave characteristics in column A with the correct term from column B. (Frames 11-17)

<u>A</u>	<u>B</u>
a. _____ A fraction which expresses that portion of a given wave which will pass a fixed point in one second.	1. Height.
b. _____ The vertical distance measured from the lowest point of the trough to the highest point of the crest.	2. Velocity.
c. _____ A figure, expressed in tens of degrees, to indicate bearing from which a wave is moving.	3. Length.
d. _____ The horizontal distance from crest to crest or trough to trough.	4. Frequency.
e. _____ The speed with which a wave crest moves through the water.	5. Amplitude.
f. _____ The vertical distance from wave crest to sea level, or from sea level to the bottom of the trough.	6. Thickness.
g. _____ The time it would take for one complete wave length to pass a fixed point.	7. Period.
	8. Direction

3. Match the wave characteristics in column A with the correct symbol used to represent each in column B. (Frames 11-17)

<u>A</u>	<u>B</u>
a. _____ Height.	L
b. _____ Velocity.	F
c. _____ Length.	A
d. _____ Frequency.	f
e. _____ Amplitude.	D
f. _____ Direction.	T
g. _____ Period.	S
	H
	C

4. In the spaces below, list the two interactions between wind and water which result in the formation and development of waves. (Frames 20-23)

5. The shaded area of the synoptic-chart sketch below depicts an area in which waves are being developed. Refer to the sketch in response to the statements immediately beneath it. (Frames 25-26)



- a. The two terms by which the area is identified are:

- b. The term used to identify the type of waves being developed in the area is:

- c. The theoretical wind criteria used to determine the area is:

6. In the spaces provided, list the three factors which determine the stage of development and the characteristics of sea waves. (Frames 28-30)

7. The following table shows the minimum fetch (F_m NM) and duration time (t_m hr.) required to generate a fully developed sea for various wind speeds (V knots). Use this table to determine the limiting factors under conditions as stated in the problems below. In the space provided, write the word FETCH, DURATION, BOTH, or NONE to indicate your solution to the problem (Frames 32-35).

V knots	10	12	14	16	18	20	22	24	26	28
F_m NM.....	10	18	28	40	55	75	100	130	180	230
t_m hr.....	2.4	3.8	5.2	6.6	8.3	10	12	14	17	20

V knots	30	32	34	36	38	40	42	44	46
F_m NM.....	280	310	420	510	600	710	830	960	1100
t_m hr.....	23	27	30	34	38	42	47	52	57

V knots	48	50	52	54	56
F_m NM.....	1230	1420	1610	1800	2100
t_m hr.....	63	69	75	81	88

a. WIND 38 kts.
 FETCH 200 NM
 DURATION 24 hrs.

LIMIT: _____

b. WIND 32 kts.
 FETCH 400 NM
 DURATION 36 hrs.

LIMIT: _____

c. WIND 16 kts.
 FETCH 30 NM
 DURATION 6.6 hrs.

LIMIT: _____

d. WIND 30 kts.
 FETCH 100 NM
 DURATION 24 hrs.

LIMIT: _____

e. WIND 12 kts.
 FETCH 60 NM
 DURATION 10 hrs.

LIMIT: _____

f. WIND 25 kts.
 FETCH 180 NM
 DURATION 8 hrs.

LIMIT: _____

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8. Select, from the following, those statements which are TRUE regarding the cause and effect of waves and wave groups becoming superimposed. Place a "T" beside those you select. (Frames 37-40)

- ___ a. When wave groups become superimposed, characteristics of the individual waves become distorted.
- ___ b. Wave groups become superimposed because of the difference in direction and velocity with which they are moving.
- ___ c. When out of phase, the combined energy of superimposed waves is working together.
- ___ d. When the crests and troughs of superimposed waves are in phase, amplitudes of the combined crests and troughs are decreased.
- ___ e. Superimposition of wave groups results in the sea's having a chaotic, or confused, appearance.
- ___ f. When the crests and troughs of superimposed waves are out of phase, amplitudes of the crests and troughs of the combined waves become dampened or flattened.

9. Complete the following statements with regard to the energy distribution, direction of movement, and conversion of sea waves. (Frames 42-49)

- a. Normal sea-wave alignment and movement is when wave crests are _____ to the dominant wind flow and move _____ to it.
- b. Deep-water waves, being unaffected by Coriolis force, always continue to move in a _____ path.
- c. When considering the combined characteristics of all the wave groups present, the total summation is referred to as the sea or energy _____.
- d. Any significant change in wind _____ and/or _____ or movement of sea waves outside their fetch area, results in conversion of the waves into _____.
- e. Because of the direct relationship between wave height, energy, and frequency, for every wind velocity there is a specific _____ around which the maximum energy will be concentrated; this is referred to as the _____.

10. In the spaces provided, list the three processes which result in the modification of wave characteristics after departing the fetch. (Frame 51-56)
- _____
- _____
- _____

11. In the space provided, write the word SEA or SWELL to indicate whether the following statements describe wave conditions within, or outside, the fetch (Frames 58-62)

- _____ a. Wave heights, periods, and frequencies cover a wide range.
- _____ b. Wave characteristics are similar and have a narrow frequency range.
- _____ c. Crest length of the wave is at least six to seven times the wave length.
- _____ d. Wave crests are sharp, angular, and irregular; distance between crests is short.
- _____ e. Wave crests are well rounded and regular; wave periods are long.
- _____ f. Crest lengths are relatively short, usually about two or three times the distance between crests.

12. Complete the following statements, with regard to the velocity of swell waves, swell groups, and the energy transfer process. (Frames 64-73)

- a. The speed of advance of individual waves within a swell group is _____ that of the entire group.
- b. As a swell wave advances within an area of calm, _____% of its energy is left behind.
- c. A swell group moves with a velocity which is equal to _____ that of its waves.
- d. Because of the energy transfer process, as a swell group advances and its leading waves die out, new waves are formed at the _____ of the group.

13. Select, from the following statements, those which are TRUE with regard to the effect ocean-current and sea wave encounters have upon swell. Place a "T" beside those you select. (Frames 75-80)
- ☐ a. Swell waves, entering and transiting a fetch at an oblique angle, will always suffer a loss of energy.
 - ☐ b. Swell-wave heights become decreased and their lengths increased when they encounter ocean currents moving in the same direction as themselves.
 - ☐ c. When swell waves encounter following or opposing ocean currents, in order for wave heights or lengths to be altered without changing periods, phase velocities must be increased or decreased proportionately.
 - ☐ d. Considering currents of equal velocity, swell-wave heights will be affected most by those currents which are moving in the same direction as themselves.
 - ☐ e. Upon encountering an ocean current moving in the same direction as themselves, swell-wave heights become increased and their lengths shortened.

End of Self-Test.

BASIC PRINCIPLES OF SEA AND SWELL

ANSWERS TO SELF-TEST

1. B, C, E.

2. a. 4
b. 1
c. 8
d. 3
e. 2
f. 5
g. 7

3. a. H
b. C
c. L
d. f
e. A
f. D
g. T

4. Pushing, dragging.

5. a. Generating area, fetch.
b. Sea waves.
c. Constant speed and direction

6. Wind speed, duration,
fetch length

7. a. Both. d. Fetch.
b. None. e. None.
c. Fetch. f. Duration.

8. a. T
b. T
e. T
f. T

9. a. Perpendicular, parallel
b. Straight
c. Spectrum
d. Direction, speed, swell
e. Frequency, $f_{\max}$

10. Energy loss, dispersion, angular spreading.

11. a. Sea d. Sea
b. Swell e. Swell
c. Swell f. Sea

12. a. Twice
b. 50
c. One-half
d. Rear

13. a. T
b. T
c. T